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Performance of relief wells during the Great Flood of 1993

by Joseph A. Kissane

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The Great Flood of 1993 in the upper Midwest exceeded previous records for flood stage at most stations and broke records for measured river flow and duration of flood throughout the region. In addition to tremendous damage to public and private property, this event allowed the evaluation of flood-control structures performing under conditions which, in many cases, exceeded their design capabilities. Many of the agricultural levees were designed to provide protection against 50-year flood events, and this flood exceeded a 50-year event by varying degrees, depending upon the river mile. In spite of this and in large part because of the tremendous efforts of flood fighters, many of the Federal agricultural levee districts within the St. Louis District remained protected.

A comparatively small, but nonetheless significant, consequence of this flooding was the prolonged flowing of relief wells along the toes of levees. This protracted flow not only acted to control underseepage but also provided an opportunity to collect data and evaluate the performance of these wells.

Design methods of underseepage control include seepage berms and relief wells. Seepage berms control underseepage by essentially lengthening the seepage path in the Darcy equation, slowing discharge to a level that will ideally not erode material. Relief wells act as preferred pathways for underseepage and reduce damages by the proper design of screen and filter to prevent passage of foundation material.

along the Mississippi River and its tributaries. Most of the wells were installed in the 1950's, prior to the availability of modern wire-wrap well screens and PVC materials. They were typically constructed with 8-in. (inside diameter), creosote-impregnated wood stave screens set at depths ranging from 60 to 110 ft (Figure 1). During the flood, two crews were employed to take flow readings and record the data necessary to calculate the hydraulic head at the toe of the levees. The performance of the wells was analyzed with these data and compared to the previous underseepage analysis (U.S. Army Corps of Engineers 1956).

Historic records of these wells indicate that they were designed and installed using underseepage equations that, by necessity, made generalized assumptions about the stratigraphic geometry of the alluvial valley. The wells were grouped into reaches believed to have similar subsurface conditions. Generalizations as to the



Figure 1. Portion of relief well riser exhumed by
levee breach in Bois Brule levee in Missouri

Background

Individual levee districts within the St. Louis District have approximately 2,500 relief wells

for public release
distribution is unlimited

length of seepage paths, hydraulic conductivity of the clay blankets (both landside and riverside), and the hydraulic conductivity of the aquifer were made for each reach of wells. Based on the analysis, the well spacing and discharge at design flood were calculated. After installation and development, each well was pump tested. Records indicate that each pump test was conducted at a constant rate of 500 gpm for 2 hr to derive a value for specific capacity. The facts that over 2,000 wells are recorded as having been tested over an 8-year period at the same rate without the slightest deviation in discharge and that photographs of this operation do not indicate a control valve on the pumps or discharge lines cast doubt on the precision of these specific capacity values (U.S. Army Corps of Engineers 1956).

Evaluation methods

Two ways of evaluating the performance of the wells during the flood were considered. If enough data were available from the flood, i.e. if two flow rates and head measurements were made, the specific capacity could be calculated and compared with that at the time of installation. About half of the wells were measured with and without standpipes in place, giving two different flow rates and corresponding heads. Suspicion as to the reliability of installation pump test records, however, led to the second alternative. The actual discharge rates measured during the flood were compared with the discharge rates calculated in the design of the system. This seems a more appropriate means of evaluating the performance, as it is an actual check on whether the wells were performing close to the intended level and does not rely on comparison with suspect data.

To compare the flow data collected during the flood to the flows calculated in the design documents, some conversion for the differences between river stage (and resulting net head) had to be made. The fundamental basis of the underseepage analysis is Darcy's Law:

$$Q = k i A$$

or

$$Q = k \left[\frac{(h_{\text{riverside}} - h_{\text{landside}})}{s} \right] A$$

where

Q = flow

k = hydraulic conductivity

i = hydraulic gradient =
 $(h_{\text{riverside}} - h_{\text{landside}})/s$

$h_{\text{riverside}}$ = hydraulic head on riverside of levee

h_{landside} = hydraulic head on landside of levee

s = seepage distance

A = cross-sectional area

All of the variables in this case are assumed constant except for the heads at riverside and landside, which are calculated using daily flood hydrographs and river gradients, and the flow, Q , which was measured in the field by mechanical rotating-vane flow meters. Comparison was then a matter of adjusting the flood discharge data to Q at the net head resulting from the design flood (either a 50-year event for agricultural levees or 500-year flood for urban protection). This was accomplished by calculating the net head during the flood and multiplying the flood discharge by a ratio:

$$Q_{\text{adj}} = A_{\text{flood}} \left[\frac{\text{net head (design)}}{\text{net head (flood)}} \right]$$

This adjusted discharge is then compared with the design discharge for each well and expressed as a percentage of design discharge.

Data collection was limited to wells that were readily accessible. Although some readings were taken in deep water from boats, these data are less useful because of the need to calculate the elevation of landside water surface and compute the net head at the well accordingly.

Visual inspection of the surface protection at well heads during the flood and prior to overtopping of levees indicated a wide range of conditions. Most well protection was intact and functioning, but some evidence of vandalism and plugging was observed. Damage by mowing or farm equipment or by varmints was also occasionally observed.

The flow data from 190 wells are shown in Figure 2. These data suggest that the wells in some districts were performing beyond their design levels, e.g. Columbia and Fort Chartres, MO, but most were operating significantly below their design performance. The limited data from the East St. Louis District may be interpreted as indicating the greatest need for rehabilitation effort. These wells are currently scheduled for major rehabilitation by contract.

Well rehabilitation during flood

During the course of the flood fight, the possibility of improving well flow to further control underseepage and reduce erosion potential at levee toes was explored by both the Cape Girardeau, MO, flood fight team led by Mark Alvey and the forces operating out of the District

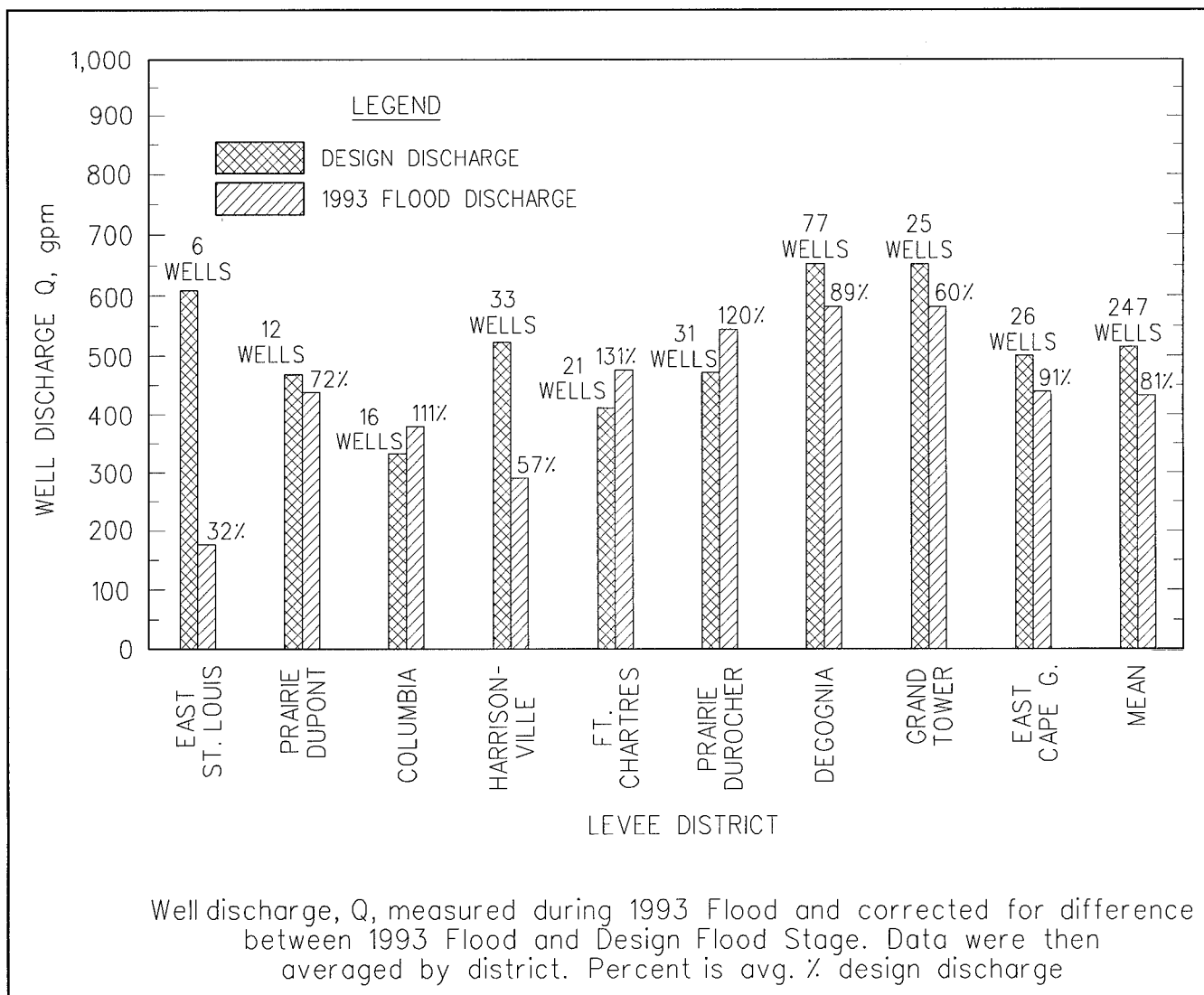


Figure 2. Bar chart of relief well discharge from 247 wells in levee districts from Alton to Gale, IL (Mississippi River levees.) Right-hand bar of each pair is the mean design discharge for the wells read within each district. Left-hand bar of each pair is the mean discharge during 1993 flood adjusted for difference between net head at design and the day of well readings discharge (grouped by district)

office in St. Louis. After discussions with Ken Klaus, on TDY from the Vicksburg District, efforts to employ air-lift redevelopment were undertaken in wells being monitored by the Cape Girardeau forces. This was done using a 185 CFM compressor, discharging near the bottom of the wells and lifting water, sediment, and bacterial sludge from the wells. Data collected during this operation indicate that some improvement in well performance resulted (Figure 3). The object of this exercise was to immediately improve well performance and reduce the threat of levee failure. Data from this effort are limited because emphasis was properly placed on reducing well performance rather than documentation.

Meanwhile, three relief wells on the upper flank of the Harrisonville Drainage and Levee District were being continuously pumped under direction of the team operating from the District office. This operation was undertaken to relieve excessive hydraulic gradients indicated by piezometer readings. The efforts resulted in noticeably firmer ground surrounding the wells and a stabilization of the gradients despite a continuously rising river stage. Unfortunately, overtopping occurred shortly after the maximum river stage charged through the Columbia District immediately upstream. However, data collected during the air-lifting operations indicated measurable increases in well flows.

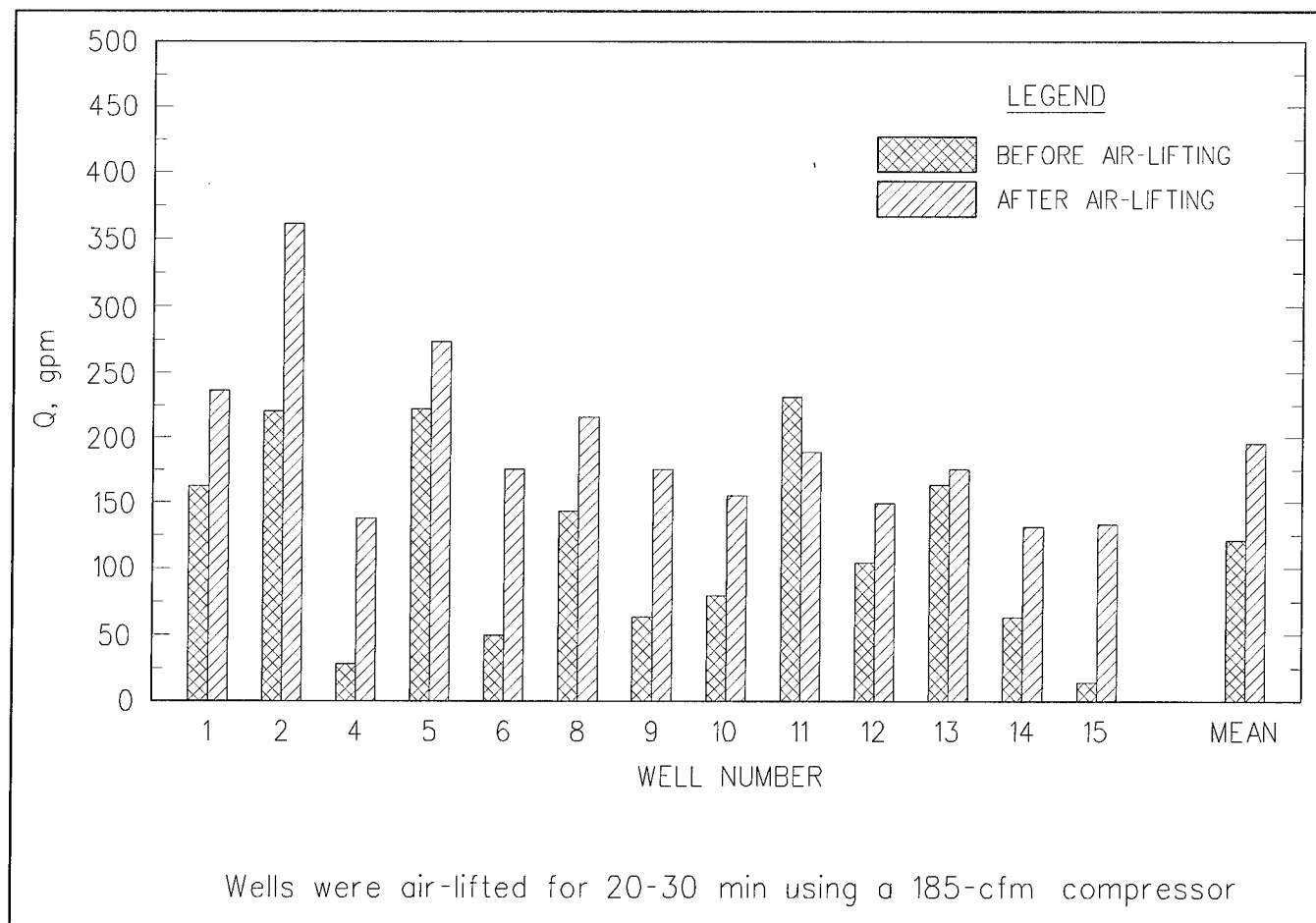


Figure 3. Bar chart of well discharge of 13 wells before and after air-lifting operation in East Cape Girardeau Drainage and Levee District (data provided by Ken Klaus, Vicksburg District)

Lessons learned

Several observations may be made regarding the performance of relief wells during this flood. The Columbia Drainage and Levee District experienced tremendous underseepage problems in spite of the fact that the relief wells there appeared to be exceeding their design flows. This may be due to the contribution of the complex soil stratigraphy of the floodplain (Smith and Smith 1984). The Bois Brule levees in Missouri failed in spite of relief wells. The levee designs incorporated data from exploration borings, and well screens were designed based on logs of borings. But the complex geometry of the shallow alluvial soils may not have been fully understood or may have been too variable for a standardized approach to underseepage control design.

Stratigraphic conditions in this region typically result in higher hydraulic conductivity values deeper in the alluvial aquifer relative to the upper portions. Flows from wells with screens penetrating into the aquifer may, therefore, originate predominantly from deeper portions of the

aquifer, where overburden pressures are such that uplift and piping are not likely to be problems. High well discharges may give the impression that high gradients across the less permeable floodplain deposits are being mitigated, when, in fact, the portion of flow from the shallower part of the aquifer may not be sufficient to accomplish this. This issue, however, was not resolved from available data.

Relief wells and seepage berms may not always be enough to protect areas during floods of this magnitude. Clearly, if the design flood stage of the levee is exceeded, the chances of its providing protection are reduced. The computations for levee stability and underseepage cannot account for changes in parameters resulting either from years of minimal maintenance or from factors such as river scour. Water velocities during flooding of this intensity may jeopardize vegetative cover on the levee berms and slopes where rock cover or armoring is not present, particularly after prolonged submersion has killed vegetation. When erosion, cultivation, excavation, or any number of other changes in landscape occur adjacent

to a levee, the seepage path may be significantly shortened, increasing underseepage. During this flood, trees and even fencepost holes provided shortened seepage paths for underseepage, particularly where clay blankets were thin or nonexistent, increasing velocities to levels which could move material.

A determination is needed of relief well conditions in levee districts which were flooded by overtopping (Columbia, Harrisonville, and Fort Char- tres, MO) and those where levees failed (Bois Brule/Perry County). Extended inundation by floodwaters carrying suspended sediment may have severely impacted well functioning, and the very real possibility exists that well head protec- tion was buried or destroyed by flooding.

Likewise, the effects of prolonged inundation by seepage water are undetermined. Earlier studies indicate that some actual improvement in perform- ance followed the flood of 1973, but the duration of this flood exceeded 1973 by several weeks, and river stages at St. Louis, MO, and Chester, IL, exceeded 1973 stages by more than 6 ft. Many well head housings may be buried by silt washed into low areas by seepage water and surface run- off from the torrential rains which fell. At the very least, the conditions of such features as well riser pipes, gaskets, and well head protective structures are in need of assessment.

Farmers and landowners not familiar with the importance of relief wells have gone to great lengths to prevent well discharges from inundat- ing their property. Easements and rights-of-way may have to be created or enforced with greater vigor, and the importance of relief well function should be re-emphasized. Surface drainage should be improved to direct seepage water away

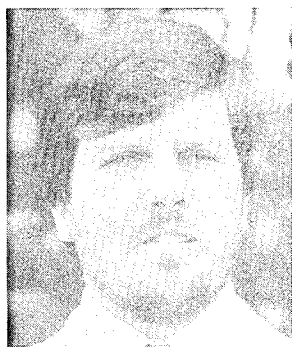
from houses and buildings and minimize negative impacts wherever possible. A means of assessing well condition and funding for maintenance and repair must be in place, or their performance will decline to a level of ineffectiveness.

In the future, the level of detailed study neces- sary to thoroughly evaluate conditions and plan relief well systems for a complete one-time con- struction contract may be cost and time prohibi- tive. An alternative to this may be to make initial evaluations of the area using the best avail- able data and computer analysis (several pro- grams are currently available). Carefully moni- tored pump tests following the first stage of instal- lation may then be used to check the performance of the system as well as the validity of the assumptions used in modelling. Using the data from well installation logs and pump tests, the design inputs to the model may be refined and additional requirements assessed.

For additional information, contact Joe Kissane at (708) 579-5940.

References

- Smith, L.M., and Smith, F.L. (1984). "Engineering geology of selected areas, U.S. Army Engineer Division, Lower Mississippi Valley; The American bottom area, MO-IL," Technical Report GL-84-14, Report 1, Vol 2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- U.S. Army Corps of Engineers. (1956). "Investiga- tion of underseepage Mississippi River levees, Alton to Gale, Illinois." Technical Memorandum TM-3-430, Washington, DC.



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Centrifuge testing of 1/20-scale landside lock wall model

by Ron Meade

During the summer of 1993, a 1/20 model of a landside lock wall constructed at the Waterways Experiment Station (WES) was tested in the 440 g-ton centrifuge at the University of Colorado at Boulder, CO. The testing was completed in October 1993, and the model was returned to WES the following month. These tests, the first of their kind, were part of the Physical Model Plan formulated under the REMR Research Program to investigate the correctness of current stability analyses of older gravity structures (see *The REMR Bulletin*, June 1993). They provided a glimpse of the promise and problems associated with centrifuge testing.

Physical characteristics of model

The model was 24 in. high and 28 in. wide, measured perpendicular to the cross section (Figure 1) with a 9-in.-wide base (measured width of the cross section). The monolith and rock foundation were modeled with simulant materials. The monolith material had a modulus of about 3 million psi, and the rock foundation had a modulus of about 0.8 million psi.

Several geometric features of the monolith require that simplifying assumptions be made in stability calculations. First, the base is stepped and is usually simplified by neglecting the step. Second, the stepped landside wall is taken as vertical. Third, a large cavity near the base is

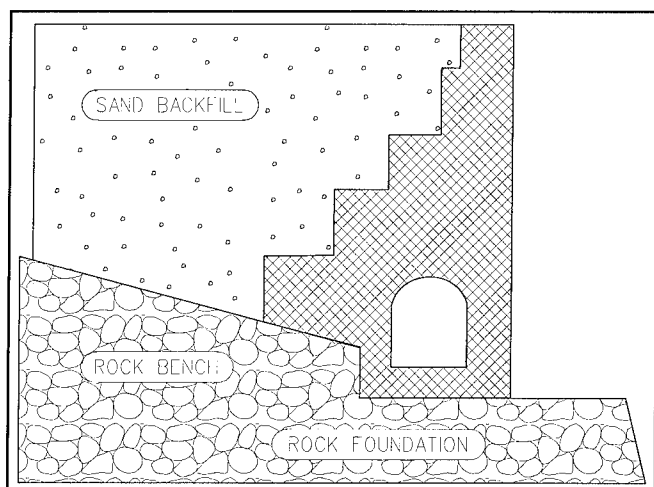


Figure 1. Cross section of the landwall monolith

ignored, and the structure is treated as a rigid body.

Figure 2 shows a free-body diagram of the structure used for stability analyses for sliding and overturning. These are limit equilibrium analyses using the forces shown on the free-body diagram. The forces are determined from assumptions made regarding the pressure distributions on the boundary of the free body. Measurement of those pressures was the goal of the experimental program.

Instrumentation

The monolith was instrumented to determine stresses and displacements at selected points. Four types of instruments were used: total stress transducers, Precision Measurements M150; total stress transducers, Precision Measurements M156 (used to measure lateral stress); fluid pressure transducers, Druck PCDR 81; and position transducers, Bourns. Locations of these instruments are given in Figure 3.

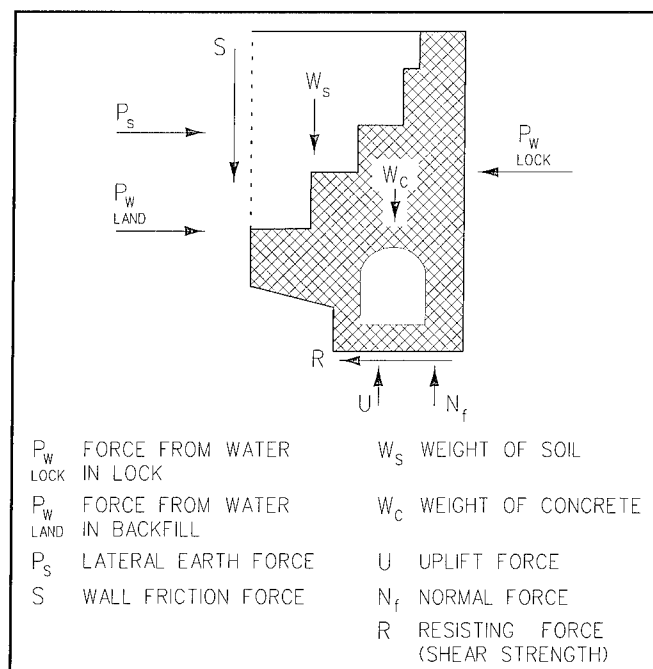


Figure 2. Free-body diagram of landside monolith

Bibliography of REMR Publications, 1992 - Present

This insert to *The REMR Bulletin* provides bibliographical information about REMR technology published since the distribution of the *Index to REMR Technology and Listing of REMR Research Publications Through March 1993* and the *Annotated Bibliography of REMR Technical Reports Through September 1992*. Bibliographical inserts will be printed periodically as an aid to effective transfer of REMR-developed technology. For copies of the reports, technical notes, material data sheets, or bulletin articles listed herein, write to Director, U.S. Army Engineer Waterways Experiment Station, ATTN: CEWES-SC-A/Technology Transfer Specialist, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, or call Lee Byrne at (601) 634-2587.

Technical Reports

Coastal applications

Ward, D.L., and Ahrens, J.P. (1993). "Use of a Rubble Berm for Reducing Runup, Overtopping, and Damage on a 1V to 2H Riprap Slope; Experimental Model Investigation," Technical Report REMR-CO-17, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

This report describes laboratory tests with irregular waves to determine wave runup characteristics and armor stability of riprap revetments. Tests include conventional, plane, 1:2 slope revetments as well as conventional revetments fronted by rubble berms. Rubble berms tested reduced the maximum runup by rather modest amounts, typically around 10 percent, but produced substantial improvement in the armor stability. These effects are discussed and quantified. This study demonstrates the need for a reliable irregular wave runup gage for laboratory studies of rough, porous coastal structures.

Key Words: berm, coastal damage, irregular waves overtopping, revetment, riprap stability, runup, waves

Concrete and steel structures

Lanigan, C.A. (1992). "Continuous Deformation Monitoring System (CDMS)," Technical Report REMR-CS-39, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MA.

An automated deformation monitoring technology known as the Continuous Deformation Monitoring System (CDMS) is described. The CDMS is capable of computing structural deformation using the Global Positioning System (GPS) survey technology while operating in a continuous fashion over time. A network of two personal computers control GPS survey equipment and process the satellite data gathered to compute apparent structural deformation up to 24 times a day without the presence of an operator. Structural monitoring can take place at the project site or at a distant office. Performance testing has determined deformation measurement precision in the sub-centimeter range. The CDMS was installed at Dworshak Dam in northern Idaho and tracked the upstream movement of the dam while it was undergoing reservoir drawdown.

Key Words: automated deformation monitoring, Continuous Deformation Monitoring System, Global Positioning System, structural monitoring

Alexander, A.M. (1993). "Impacts as a Source of Acoustic Pulse-Echo Energy for Nondestructive Testing of Concrete Structures," Technical Report REMR-CS-40, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

No method presently exists to probe the deep interior of large concrete structures such as locks and dams. This report describes a research investigation to determine the feasibility of using impacts to create high-energy, high-resolution stress waves for making sonic and ultrasonic pulse-echo (UPE) measurements in concrete. Impacts from air guns that shoot steel balls, the Schmidt rebound hammer, and small explosives demonstrate the potential for generating the appropriate kind of energy for UPE measurements. Measurements were made to demonstrate that the frequencies generated by these types of impacts are in the proper range for making UPE measurements in concrete, i.e. less than 200 kHz. Also, it was demonstrated that the energy level from these impact sources was high, suitable for penetrating large distances. Various criteria discussed in this study have a bearing on the development of a practical impact UPE system for concrete structures.

Key Words: concrete, construction, impact-echo, nondestructive testing, pulse-echo, resonant frequency, sonics, ultrasonics

Miles, W.R. (1993). "Comparison of Cast-in-Place Concrete Versus Precast Concrete Stay-in-Place Forming Systems for Lock Wall Rehabilitation," Technical Report REMR-CS-41, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

This report is the product of an after-action study performed on the use of a precast concrete stay-in-place forming system for lock chamber rehabilitation at Troy Lock and comparison with previous cast-in-place repairs. Listed herein are pertinent background information, design criteria, panel details, production data, installation details, and quality and economic comparisons with cast-in-place rehabilitation. The precast system used at Troy Lock was installed at a cost slightly lower than that of cast-in-

place systems used previously, but with substantial improvements in appearance, speed of construction, and extent of cracking.

Key Words: navigation structures, precast concrete, rehabilitation, stay-in-place forms, Troy Lock and Dam

Campbell, R.L., Sr. (1994). "Overlays on Horizontal Concrete Surfaces: Case Histories," Technical Report REMR-CS-42, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

This study documents the current practices for overlaying horizontal concrete surfaces as a first phase in the development of performance criteria for concrete overlays. The case histories presented are typically for overlays completed within the last 10 years and located at Corps of Engineers civil works projects. Overlays documented in the report include bonded conventional, low-slump, fly-ash, silica-fume, polymer-modified, and fiber-reinforced concretes. Unbonded overlays are also documented. Although the information obtained for each case history varied and was sometimes limited, an attempt was made to provide the following basic information for each repair: (a) project description, (b) cause and extent of damage, (c) description of repair materials and procedures, (d) cost, and (e) performance of repair.

Key Words: polymer-modified concrete, silica-fume concrete, thin overlay, unbonded overlay

Bower, J.E., Kaczinski, M.R., Zouzhang, M., Zhou, Y., Wood, J.D., and Yen, B.T. (1994). "Structural Evaluation of Riveted Spillway Gates," Technical Report REMR-CS-43, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Guidelines are presented for structural inspection and evaluation of riveted spillway gates. An overview of the structural systems of most common types of spillway gates is provided along with identification of critical areas that may be subject to degradation from corrosion and/or fatigue damage for each type of gate. Observations from site inspections at four locks and dams are included. The principal factors contributing to corrosion and fatigue degradation of spillway gates are presented. Guidelines are provided for the evaluation of corrosion and fatigue damage. A structural inspection and evaluation procedure is outlined.

Critical areas and techniques for inspection and reporting are discussed along with evaluation procedures. Two example inspections and evaluations are provided to illustrate the procedures.

Key Words: corrosion, evaluation, fatigue, inspection, riveted spillway gates

Commander, B.C., Schulz, J.X., Goble, G.G., and Chasten, C. (1994). "Field Testing and Structural Analysis of Vertical Lift Lock Gates," Technical Report REMR-CS-44, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

The objective of this study was to measure the behavior of vertical lift lock gates experimentally and to develop modeling and analysis procedures for the evaluation of existing gates and design of new gates. In this study, lift gates at Mississippi River Lock 27 and Locks and Dam 26 were investigated. The gates were instrumented and tested under various loading conditions, and analytical models were developed to simulate structural response of each.

Key Words: analysis, boundary condition, data comparison, design, evaluation, head differential, loading condition, modeling, strain

Commander, B.C., Schulz, J.S., Goble, G.G., and Chasten, C.P. (1994). "Detection of Structural Damage on Miter Gates," Technical Report REMR-CS-45, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

The primary goal of this study was to develop structural evaluation tools that can be used to assess the current condition of aging steel lock gates. In this report, an integrated experimental and analytical system is evaluated to determine if such a system could be used in identifying existing structural damage on the basis of comparing measured and calculated strain data without having information from prior detailed structural inspections. The integrated system proved to be valuable in both damage detection and assessment. Various types of damage were detected directly from measured strains and further verified by comparing the strains with computed values. When structural damage was identified, either from test data or by other means, the cause or effect of the damage could usually be explained with the aid of analytical procedures. However, at this time, the assessment process cannot be fully automated because considerable engineering judgment and experience are required to interpret and evaluate the results.

Key Words: Emsworth Lock and Dam, evaluation system, Mississippi River Locks and Dam No. 26, Mississippi River Locks and Dams No. 27, miter gates, numerical modeling, Red River Lock and Dam No. 1, steel structures

Geotechnical applications

King, R.L., and Miller, W.O. (1992). "DAMSEAL - an Expert System for Evaluating Dam Seepage," Technical Report REMR-GT-19, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

This report documents an expert system containing the Corps of Engineers' best diagnostic capabilities for seepage analysis and control at dams. This capability was achieved through exhaustive interviews and workshops with those geotechnical engineers/geologists identified by the Office, Chief of Engineers as being expert in remedial seepage analysis. DAMSEAL is written in the Level 5 Expert System Shell and gives access to the existing Corps of Engineers' DAMS database using dBase III. Another database, Seepage.dbf, contains information on dams that have experienced seepage problems. DAMSEAL is a self-contained system with no other software requirements. Hardware requirements are an IBM-compatible PC, 640 RAM, and a hard disk with 2 MB of available memory.

Key Words: abutments, artificial intelligence, dams, database, expert systems, foundations, remedial actions, seepage

Shannon and Wilson, Inc. (1993). "Evaluation of Overturning Analysis for Concrete Structures on Rock Foundations," Technical Report REMR-GT-20, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

This report includes discussions of the present method of overturning analysis and the underlying assumptions; the contact stresses under the base of the structures; and the effects of strain compatibility, compaction-induced lateral stresses, and wall friction on the driving and resisting moments. Recommendations are made for modifications to the present method of analysis. Areas for future studies where additional improvements could be made are also discussed.

Key Words: gravity structures, lateral stresses, stability, strain compatibility, stresses, wall friction

Shannon and Wilson, Inc. (1993). "Incorporation of Wall Movement and Vertical Wall Friction in the Analysis of Rigid Concrete Structures on Rock Foundations," Technical Report REMR-GT-21, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

This report presents recommendations for modification to the present Corps of Engineers' stability analysis for concrete gravity structures. These modifications are intended for use in conjunction with the current analysis procedures for a more accurate assessment of the factor of safety of existing structures. It is concluded from this study that the effects of wall friction and strain

compatibility are significant when the foundation rock modulus is relatively low.

Key Words: gravity structures, stability, strain compatibility, wall friction

Hydraulics

Berger, R.C., and Alexander, M.P. (1993). "Design Criteria for Lateral Dikes in Estuaries," Technical Report REMR-HY-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Guidelines for lateral dike spacing were developed at the Waterways Experiment Station. The guidance was based on laboratory flume analyses and applies to dikes designed for channel maintenance. Various dike plans were tested to develop energy loss versus dike length-to-spacing relationships, and spacing guidelines are presented in the form of a design outline. The testing program also included alternating dikes versus dikes positioned directly across from each other in the flume channel test section and angled dike field entrance dikes as an energy loss reduction measure.

Key Words: Dike spacing, estuaries, lateral dikes, navigation maintenance, training structures

Haynes, F.D., Haehnel, R., and Zabiansky, L. (1993). "Icing Problems at Corps Projects," Technical Report REMR-HY-10, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

During cold weather, icing of machinery such as dam gates, lock gates, gears, and seals is a problem at Corps projects. A survey was distributed to Divisions and Districts to obtain information on icing problems and existing solutions. Results of the survey are presented in this report. Each solution is discussed in relation to the appropriate problems.

Key Words: bubbler, dams, gates, ice, icing, locks, machinery

Bernard, R.B. (1993). "STREMR: Numerical Model for Depth-Averaged Incompressible Flow," Technical Report REMR-HY-11, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MA.

The STREMR computer code is a two-dimensional numerical model for depth-averaged incompressible flow. It accommodates irregular boundaries and nonuniform bathymetry, and it includes empirical corrections for turbulence and secondary flow. Although STREMR uses a rigid-lid surface approximation, the resulting pressure is equivalent to the displacement of a free surface. Thus, the code can be used to model free-surface flow wherever the local Froude number is 0.5 or less. STREMR uses a finite-volume scheme to discretize and solve the governing equations for primary flow, secondary flow, and turbulence energy and dissipation rate. The turbulence equations

are taken from the standard k- turbulence model, and the equation for secondary flow is developed herein. Appendices to this report summarize the principal equations, as well as the procedures used for their discrete solution.

Key Words: depth-averaged models, incompressible flow, mathematical models, secondary flow, subcritical flow, turbulence models

Perry, E.B. (1994). "Proceedings of REMR Workshop on Levee Rehabilitation," Unnumbered, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

This report presents the proceedings of a REMR Workshop on Levee Rehabilitation held February 1992 at WES. The workshop was conducted to stimulate exchange of ideas and information regarding innovative methods for levee rehabilitation, directions for analytical and laboratory research, and possible field demonstrations of innovative methods. The presentations include seismic damage to levees, lime stabilization of levee slides, use of geogrids for levee slope repair, use of rock-fill trenches to stabilize levees, use of geotextiles for levee construction on soft soils, and soil nailing for slope repair.

Key Words: earthquakes, erosion, fly ash, geogrids, geotextiles, levee rehabilitation, lime stabilization, overtopping, seepage, slope stability, soil nailing

Operations management

Greimann, L., Stecker, J., and Rens, K. (1993). "REMR Management Systems—Navigation Structures; Condition Rating Procedures for Sector Gates," Technical Report REMR-OM-13, U.S. Army Construction Engineering Research Laboratories, Champaign, IL.

This report provides a uniform procedure to describe the current condition of sector gate structures. The inspection and rating process is based on a field inspection of the sector gate structure. During this inspection, current physical attributes of the systems are obtained. Pertinent data (gate location, inspection and maintenance histories, and historical water level) are recorded on an inspection form. The form includes space for entering field measurements (anchorage movements, elevation changes, gate deflection, cracks, dents, and corrosion), which are used to calculate a condition index, or numerical measure from 0 to 100, of the current state of the structure. The index is meant to focus management attention on those structures most likely to warrant immediate repair or further evaluation, and can be used to monitor change in the general condition over time and to serve as an approximate comparison of the condition of different structures.

Key Words: condition indexes, evaluation methodology, locks and dams, management system, sector gates

Greimann, L., Stecker, J., and Veenstra, J. (1994). "REMR Management Systems—Navigation Structures; Condition Rating Procedures for Tainter and Butterfly Valves," Technical Report REMR-OM-14, U.S. Army Engineering Research Laboratories, Champaign, IL.

This report presents the development of condition rating procedures for tainter and butterfly filling and emptying valves for navigation lock structures. Several site visits and field investigations were conducted, experts from the U.S. Army Corps of Engineers were asked to rate the valves, and the results were compared to a preliminary version of the rating system. Modifications were made to reflect the experts' opinions more accurately. A general description of the current inspection and rating system is given. This includes the definition of a condition index and a description of valve distresses. A detailed description of an inspection is provided. Once the inspection data are gathered, condition indexes for valves can be computed.

Key Words: condition indexes, locks and dams, management systems, navigation structures, valve distresses

Greimann, L., Stecker, J., Rens, K., and Nop, M. (1994). "REMR Management Systems—Navigation Structures, User's Manual for Inspection and Rating Software, Version 2.0," Technical Report REMR-OM-15, U.S. Army Engineering Research Laboratories, Champaign, IL.

A goal of the REMR Research Program is to provide procedures for performing condition surveys, consistent and quantitative condition assessments, and database management that can help managers perform efficient maintenance and repair planning. Collectively, these procedures are called the REMR Management Systems. This User's Manual describes how to use the software associated with the REMR Management Systems for miter lock gates, emptying and filling valves, sector gates, and steel sheet pile.

Key Words: condition indexes, economic analysis, miter lock gates, sector gates, steel sheet-pile structures, software

Bulletin Articles

Vol. 10, No. 2, June 1993

"Use of a Current Deflector Wall for Eddy-Generated Shoaling in Kohlfleet Harbor, Germany," by M. P. Alexander

"Coastal Structure Inspection in Wake of Hurricane Iniki," by J. A. Melby and G. F. Turk

"Geomechanical Modeling of Concrete Gravity Structures: the Physical Model Plan," by R.B. Meade and R.D. Bennett

Vol. 10, No. 3, September 1993

"Innovative Methods for Levee Repair," by E.B. Perry and M. Myers

"Use of Blended Chemical Heat Treatment (BCHT) Procedure to Clean Contaminated Wells on Superfund Sites," by B. Rogers and R. Leach

"Use of Ground-Penetrating Radar in Nondestructive Testing for Voids and Cracks in Concrete," by F.H. Ahmad and R. Haskins

Vol. 10, No. 4, December 1993

"Geomembranes for Repair of Concrete Hydraulic Structures," by J.E. McDonald

"Toe Stability in a Combined Wave and Flow Environment," by E.R. Smith

"Heated Water Jet for Melting Ice," by F.D. Haynes

Vol. 11, No. 1, April 1994

"Guides Help Standardize Lead Paint Removal," by A.D. Beitelman

"Metallized Coatings for Repair and Maintenance of Hydraulic Structures," by T. Race

"Panel Heaters Used to Control Ice Growth Caused by Fluctuating Water Levels," by F.D. Haynes, R. Haehnel, and L. Zabilansky

"Panel Wall Heaters Successful at Starved Rock Lock and Dam, Illinois River," by F.D. Haynes

Vol. 11, No. 2, July 1994

"Increasing Efficiency in a Sandbagging Operation," by G.F. Turk and P.F. Hadala

"STREMR: Model for Evaluation of Near-Field Turbulent Flow Conditions," by M.L. Schneider and R.S. Bernard

"Surveys of Concrete Armored Coastal Structures," by J.A. Melby and G.F. Turk

Vol. 11, No. 3, September 1994

"Performance of Relief Wells During the Great Flood of 1993," by J.A. Kissane

"Centrifuge Testing of 1/20-Scale Land-side Lock Wall Model," by R. Meade

Technical Notes

CS-ES-1.11 - Interim fracture and Fatigue Analysis for Aging Steel Miter Gates

CS-ES-1.12 - Guidelines for Assessing Condition of Riveted Spillway Gates

CS-ES-2.8 - Predicting Concrete Service Life for Cases of Freezing and Thawing deterioration

CS-MR-1.14 - Concrete Removal Techniques: Selection

CS-MR-4.5 - Spall Repair

CS-MR-7.4 - Selection of Concrete Exterior Wall Coatings

HY-N-1.9 - Icing Reduced with Miter Gate Recess Wall Heaters

HY-N-1.10 - Icing Reduced with Plastic on Miter Gate Recess Walls

CO-RA-1.2 - Concrete Armor Unit Performance Survey

CO-RR-1.3 - Reduction of wave Runup on a Revetment by Addition of a Berm

CO-RR-1.6 - Movement and Static Stresses in Dolosse

EM-PC-1.5 - Evaluating Aged Red Lead Coating Systems for Service-Life Extension

OM-MS-1.7 - REMR Management System for Sector Gates

OM-MS-1.8 - REMR Management System for Emptying and Filling Valves

OM-MS-1.9 - REMR Management System for Riverine Training Dikes

Material Data Sheets

CM-CR-1.3 - Epoxy Resin System for Dormant Crack Repair: Brutem 78

CM-LA-1.4 - Latex Admixture for Portland-Cement Concrete and Mortar: Acryl-Set

CM-PC-1.10 - Concrete Patching Material: Ceilcote 646 Underwater Grout

CM-PC-1.12 - Concrete Patching Material: Ceilcote 665 Epoxy Mortar

CM-PC-1.20 - Concrete Patching Material: Masterfill CJ

CM-SE-1.2 - Concrete Sealer: Consolidation SX

CM-SE-1.15 - Concrete Sealer: Thompson's Water Seal

CM-SE-1.16 - Concrete Sealer: Bridge 10

CM-SE-1.23 - Concrete Sealer: Masterseal GP

CM-SE-1.24 - Concrete Sealer: Sil-Act ATS 42

CM-SE-1.25 - Concrete Sealer: Clear Cladding

CM-SE-1.26 - Concrete Sealer: Mark 124

CM-SE-1.30 - Concrete Sealer: HD-36 Decktreat

CM-SE-1.32 - Concrete Sealer: HEY'D1 Siloxan

CM-SE-1.38 - Concrete Sealer: UNITILE SEALER

CM-SE-1.41 - Concrete Sealer: MONOCRYL 50

CM-SE-1.45 - Concrete Sealer: DOW CORNING 3-5035

CM-SE-1.49 - Concrete Sealer: TRANSPOT 41S

CM-SE-1.56 - Concrete Sealer: C-15 Pebble Sheen

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CM-SE-1.68 - Concrete Sealer: Sika-Pronto 19

REMR Fact Sheets

Methods for Levee Repair (August 1993)

Reducing Icing on Miter Gates Recess Walls (January 1994)

Trenchless Technology - Mini-Horizontal Directional Drilling (March 1994)

Trenchless Technology - Microtunneling (March 1994)

Material Database

A listing of REMR publications is available on the Corps of Engineers Repair Products Database for Concrete and Steel Structures. Use the following telecommunication parameters to access the data base:

Baud Rate: 1200 or 2400
Data Bits: 8
Phone No.: (601) 634-4223
Emulation: VT-100
Stop Bits: 1
Parity: None

The database is menu drive and has help windows to facilitate its use. There are no restrictions regarding who may access the database. The only cost to the user is the charge for the long distance call.

Searches may be made by subject, topic, author, or title. For additional information on the database, contact Roy Campbell at (601) 634-2814, or write Director, U.S. Army Engineer Waterways Experiment Station, ATTN: CEWES-SC-CA/Roy L. Campbell, Sr., 3909 Halls Ferry Road, Vicksburg, MS 39180-6199.

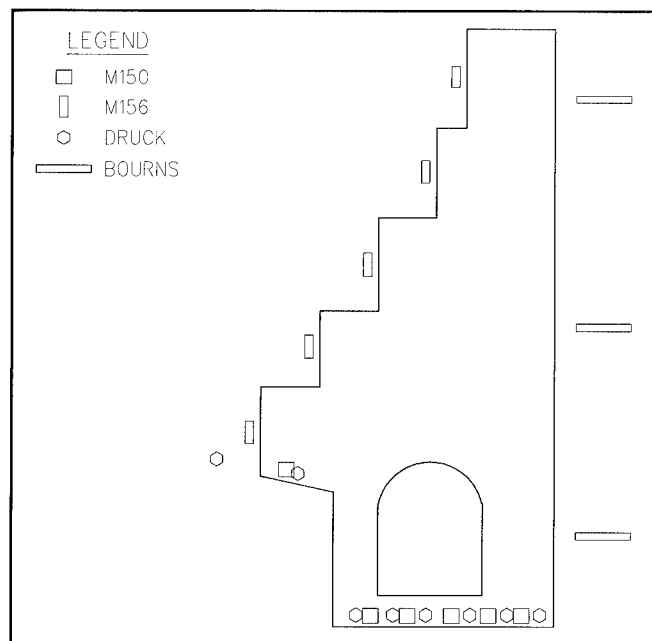


Figure 3. Location of gages

Calibration

All of the gages were calibrated under static loadings prior to centrifuge testing. The total stress gages were calibrated in a water-filled triaxial cell, and some were further tested in a sand-filled CBR mold to measure a load produced by a jack acting on a steel plate on the sand surface.

The uplift pressure gages were also calibrated in a water-filled triaxial cell. The position transducers were calibrated using a differential screw to produce accurate displacements. Some of the gages were recalibrated or subjected to further testing after the centrifuge testing. The power source for all of the calibration testing was a Vishay Model 2110 signal conditioning unit, and the signal was read on a Fluke 8020A Multimeter. The gages were very stable with the exception of one M150 and one M156, which seemed to be unstable in water. The suspect M156 gage was used near the top of the monolith where it would not be immersed in water during any of the testing. The faulty M150 behaved as if it were leaky. That is, the gage would slowly shed load when subjected to fluid pressure in excess of 20 psi. About half of the testing was to be performed dry, so the leaky gage was cast into the base with the other M150 gages.

Test series

The model was subjected to an acceleration of 20 g in the centrifuge. It was tested under three

sets of boundary conditions for a total of eight flights. In the first series, the structure alone was tested (two flights). In series two, sand backfill was placed against the structure (two flights). During series three, water was added to the sand backfill (four flights). In each of these tests, data were taken at 1, 5, 10, 15, and 20 g. In one of the tests, the model was spun at 40 g after completing the 20-g measurements.

Data acquisition system

During the centrifuge testing, the readings were recorded by means of the data acquisition system that is a component of the Colorado Data Systems modular data acquisition hardware. This system provided input power to the gages and amplified and digitized the signal from the gages prior to being piped through the slip rings of the centrifuge to a personal computer, where the data were stored and displayed.

The gages were warmed up for at least 30 min prior to each flight. Readings were taken prior to, during, and after spinning. During the dry flights, the centrifuge was accelerated to 5 g, then increased to 10 g, then 15 g, and finally 20 g. At each of these levels, the centrifuge was held at a constant g, within 0.1 g, for several minutes, during which time readings were taken. After the readings were taken at 20 g, the centrifuge motor was turned off, and the machine returned slowly to a stop. Readings were taken during the increases in g level and during the shut down.

The readings taken just prior to spinning provided an indication of the noise on each channel. In addition, the readings provided a zero point for each gage. Each flight took about 40 min to complete. The readings taken after the machine stopped spinning provided another estimation of zero. During the wet flights, the centrifuge was spun up to 20 g and held there for several minutes before being shut down. Data were taken continuously during the wet flights.

Results of series one (structure alone)

During the first series of tests, the structure moved less than 0.005 in. The displacement measurements were relative to the movement of the wall of the container. It is not known how the container deflected during the flight; the movements were so small that no general statement can be made with regard to the deflection of the monolith. The distance between the monolith and the container wall decreased; that is, the monolith

seemed to move towards the interior of the lock. The base moved more than the top, as if to slide off the rock bench.

Results of series two (structure plus sand)

In series two, the position gages recorded movement similar to the motion in series one. The sensors on the stepped back of the structure recorded the lateral pressure of the sand on the wall. The back of the wall has five steps. Two gages were mounted against the vertical face of the bottom step, and one gage was mounted against each of the other four steps.

The first flight of this series produced greater lateral stresses than the second flight. On the second flight, the gage mounted on the third step (measured from the top) recorded very small lateral stress (Figure 4). Current guidance for selection of a lateral earth-pressure coefficient is to assume a value of 0.5. The measured value of lateral earth pressure was about 0.2. The lateral earth pressure was less than 1/2 of the value generally used in stability analyses.

Results of series three (structure, sand, and water)

During the third series, the position gages recorded a motion pattern different from test series one and two. The structure appeared to move toward the backfill. As in the two previous series, the bottom-most gage recorded the most motion. However, unlike the two previous series,

the middle gage recorded the least motion. The data could indicate that the structure twisted slightly. A pattern of showing the greatest motion in the bottom and the least motion in the middle was present in all four flights of series three. The first flight showed about four times the motion of the three final flights.

The fluid pressure gages recorded the uplift pressure during the four wet flights. The depth of water in the backfill was not controlled during the flight. The same weight of water, 60 lb, was present in the backfill at the start of each flight. The prototype (full-sized) height of the structure being modeled was 40 ft, that is, 2-ft actual height of the model multiplied by 20 at 20 g. The prototype height of rock bench was 13.3 ft. The prototype water elevation with the base of the structure as datum was 21.65 ± 0.7 ft. In model dimensions, the depth was 13 ± 0.4 in. The data from the four flights comprising series three were examined as two groups. One group had backfill water level near 22 ft (prototype dimension), and the other group had backfill water level near 21 ft. The grouping was required because more gages were available than reliable channels. Two flights were required to poll all the uplift pressure gages.

The uplift pressure decreased across the base of the structure from the backfill edge to the lock interior edge. The uplift pressure measured on the gage on the rock bench was about 70 percent of headwater pressure in the backfill. Pressure at the landside edge of the base was about 30 percent of the headwater pressure. Along the central portion of the base, the uplift pressure was about 13 percent of headwater pressure in the backfill, and at the lock interior edge, it was about 2 percent of the headwater pressure (Figure 5). The measured pressures were far less than the usual values assumed in analyses. The usual assumption for the dewatered condition is that the uplift pressure varies linearly from the pressure in the backfill to zero at the lock chamber. The measured values decreased much more rapidly than assumed. The average head causing uplift using the conventional assumptions is 50 percent of the backfill head. The average head measured beneath the structure was about 23 percent of the backfill head.

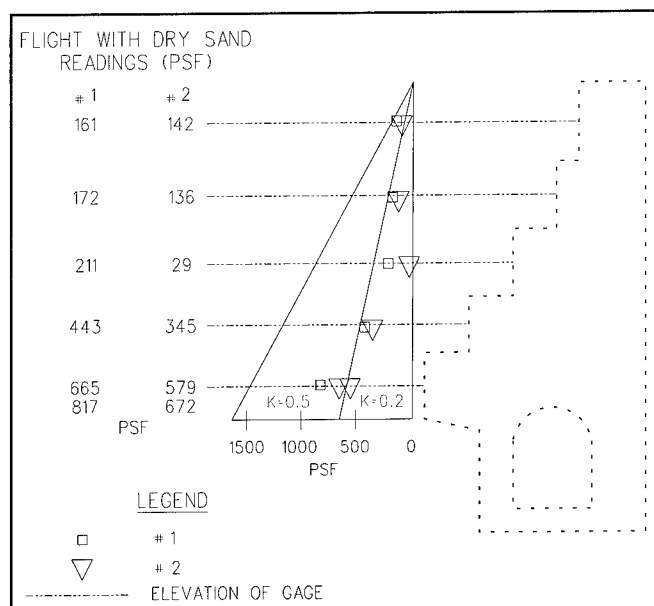


Figure 4. Lateral earth pressures

Summary

The M156, Druck, and Bourns gages provided some useful data. During series two, the M156 gages recorded lateral earth pressures that were 40 percent less than the usual values assumed in

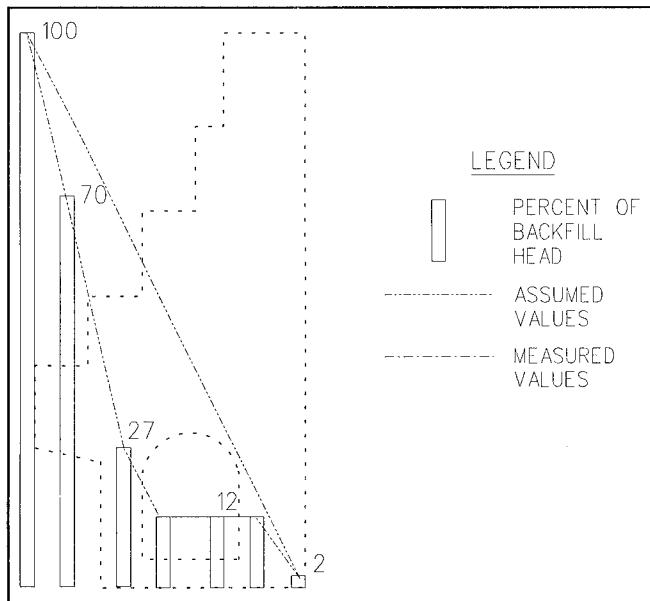


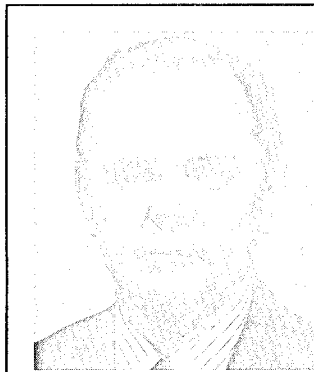
Figure 5. Uplift pressure

analysis. The effect of container stiffness on the measured lateral stresses was not determined.

The Druck gages measured uplift pressures that were less than half of the pressures normally assumed in analyses. The Bourns gages showed that the structure was stable under all loading conditions. The conventional assumptions would have implied that portions of the base were in tension during series two and three. In series three, uplift would have been assumed as 100 percent of the backfill pressure over the portion of the base in tension. The measured pressures show this to be incorrect.

Conclusions

- The structure was stable during the entire test sequence.



Ron Meade is a consulting engineer currently on contract with WES. He received BSCE, MSCE, and PhD degrees from Purdue University. He is a registered Professional Engineer in the States of Mississippi, Virginia, and Indiana. Meade is a member of the American Society of Civil Engineers, the National Society of Professional Engineers, and the U.S. Committee on Large Dams.

- The M150 gages were not suitable to measure contact stresses between two solids.
- The M156 gages were reliable in dry conditions and unreliable in wet conditions.
- The Druck and Bourns gages were reliable.
- The uplift pressures were much less than the pressures assumed in analyses.
- The lateral earth pressures were much less than those assumed in analyses.
- Complex boundary conditions can be replicated within the centrifuge.

The centrifuge is effective in demonstrating the kinematics of failure. Future work should aim at investigating failure. Configurations of structures that are unstable under analyses should be constructed with falsework and then have the falsework removed. In some cases, the falsework can be instrumented to identify the safety margin provided by the falsework. When failure does occur, the kinematics can be observed.

For additional information, contact the REMR Principle Investigator, Yogi Miller, at (601) 634-3147.

Upcoming events

Call for papers for Second International Conference on Alkali-Aggregate Reaction

The Second International Conference on Alkali-Aggregate Reaction will be held in Chattanooga, TN, on 22-27 October 1995. This conference is sponsored by the United States Committee on Large Dams (USCOLD).

Corps members are encouraged to attend the conference and to submit relevant papers for consideration for presentation. Managing alkali-aggregate reaction in existing concrete dams and hydroelectric plants is a very timely subject, and the information to be presented will have direct application to the missions of the Corps.

For additional information regarding the conference and submission of papers, contact Dr. Tony C. Liu (CECW-EG) at (202) 272-0222 (FAX (202) 272-0413).

Eighth Annual Conference on Industrial Lead Paint Abatement and Removal scheduled

The Eighth Annual Conference on Industrial Lead Paint Abatement and Removal will convene on January 30 - February 1, 1995, at the Marriot Airport Hotel in St. Louis, MO. This conference is sponsored by the Steel Structures Painting Council (SSPC) and will include sessions on lead paint removal and compliance with regulatory requirements. Exhibits will feature new technology, equipment, and products. For additional information, call Renee R. Moldovan, SSPC Conference and Training Department, at (412) 687-1113 or FAX (412) 687-1153.

Tony Kao retires

After more than 30 years with the Corps of Engineers, Anthony M. Kao retired on 30 September 1994. Dr. Kao had served as leader of the Operations Management Problem Area since the inception of the REMR Research Program in 1985 and was instrumental in the development of condition indexes for navigation structures.

Dr. Kao was a research structural engineer and a team leader in the Engineering and Materials Division of the U.S. Army Construction Engineering Research Laboratory (CERL), Champaign, IL. Prior to coming to CERL in 1971, he had worked as a



structural engineer for 8 years with the Illinois and Iowa Department of Transportation and had taught for 3 years at Saint Louis University and South Dakota State University.

Dr. Kao received B.S. and M.S. degrees in civil engineering from the University of Illinois and a PhD degree in structural engineering from Iowa State University. He is a member of the American Society of Civil Engineers and the American Concrete Institute and is a Registered Professional Engineer in the State of Illinois.

We will miss Dr. Kao's leadership and expertise and wish him well in his retirement.

Bibliography of REMR publications available on-line

A new database has been installed on the host computer for the REMR Maintenance and Repair Materials Database. In addition to providing product-performance information, the host computer now includes a bibliography of REMR publications. This addition to the database serves as a way to share REMR-developed technology with the public.

Now, the user has on-line access to publications that describe REMR technology in six broad subject areas (concrete and steel, coastal, hydraulics, electrical and mechanical, geotechnical, and operations managements). These works include technical reports, technical notes, material data sheets, and video reports printed under the REMR logo. More than 500 entries are currently available, and new entries will be added periodically. Points of contact for obtaining copies of

these publications are given. Bibliographical searches are made through key words.

The database is very user-friendly; it is menu driven and has help windows to facilitate its use. Access to the database is not restricted, and there is no charge for its use, other than the cost of a long-distance telephone call.

The database is accessed through a 386 (or higher) personal computer with a modem. The telecommunications parameters are as follows: baud rate - 1200 or 9600; data bits - 8; duplex - full; emulation - VT-100; stop bits - 1; parity - none.

For additional information, contact Roy L. Campbell, Sr., by calling (601) 634-2814 or writing Director, U.S. Army Engineer Waterways Experiment Station, ATTN: CEWES-SC-CA/Roy Campbell, Sr., 3909 Halls Ferry Road, Vicksburg, MS 39180-6199.

Sixth REMR-II Field Review Group Meeting held in Washington, DC

Meeting milestones and getting the information out to the field were the challenges directed to the Corps Laboratories by the REMR-II Field Review Group (FRG) at the sixth annual meeting held 16-28 August 1994 in Washington, DC.

During the 2-1/2 day session, problem area leaders and principal investigators gave slide presentations on each of the on-going work units under the six REMR problem areas: coastal, concrete and steel, electrical and mechanical, geotechnical, hydraulic, and operations management. Each presentation covered the problems being addressed, objectives, approach, products, progress to date, and anticipated benefits.

Some of the new technologies being developed under the auspices of the REMR Research Program include CORE-LOC, an innovative armor unit for repair of coastal breakwaters and jetties; SEABAT, an improved multibeam sonar for monitoring underwater structures, both during and after construction; HIVELED2D, a two-dimensional model to evaluate supercritical flow in a high-velocity channel; the "aluminum sandwich" heater panel for controlling icing at locks and dams; guidance in lead paint abatement; and development of more environmentally acceptable lubricants for use in hydroelectric units. Condition indexes that have been added to the Operations Management System during FY94 include procedures for tainter and butterfly valves (in field review); concrete in gravity dams, retaining

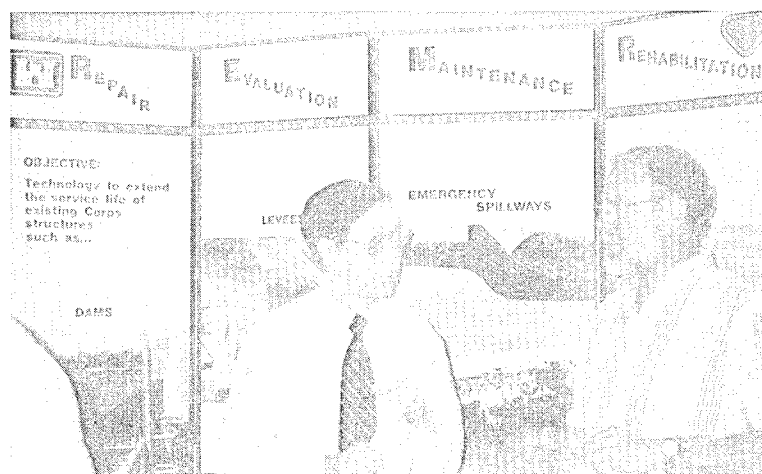
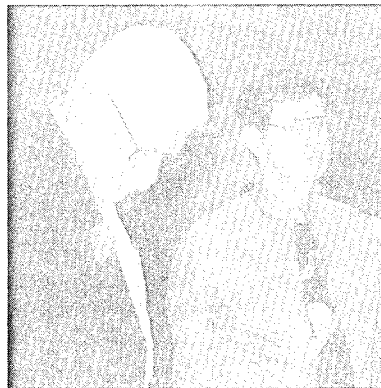
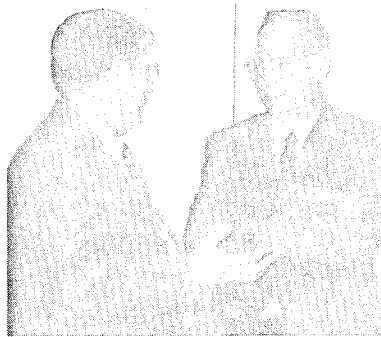
walls, and spillways (in field review); tainter dams and lock gates (printed); and a user's manual for inspection and rating software, version 2.0, for miter lock gates, emptying and filling valves, sector gates, and steel sheet pile (printed).

Eighteen unfunded requirements were presented for consideration and were rated by FRG members and Technical Monitors. These ratings were used by the REMR Overview Committee and Program Manager to determine which would be funded in the FY95 REMR-II Program. The

six new starts that were approved include (1) development of advanced thermal spray methods and materials, (2) innovative concrete systems for rehabilitation and replacement of hydraulic structures, (3) a three-dimensional flow simulation package, (4) detection of blast damage in production of construction stone, (5) determination of in situ permeability of slurry trenches, and (6) evaluation of low-environmental-impact grouts.

Other suggestions made during the meeting included consideration of cost-sharing opportunities with other Government agencies and private sector companies, annual summaries of REMR products, and increased tech transfer on lessons learned.

The seventh REMR-II FRG Meeting will be held July 1995 at a location to be determined. For additional information, contact Lee Byrne at (601) 634-2587.





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The *REMR Bulletin* is published in accordance with AR 25-30 as one of the information exchange functions of the Corps of Engineers. It is primarily intended to be a forum whereby information on repair, evaluation, maintenance, and rehabilitation work done or managed by Corps field offices can be rapidly and widely disseminated to other Corps offices, other US Government agencies, and the engineering community in general. Contribution of articles, news, reviews, notices, and other pertinent types of information are solicited from all sources and will be considered for publication so long as they are relevant to REMR activities. Special consideration will be given to reports of Corps field experience in repair and maintenance of civil works projects. In considering the application of technology described herein, the reader should note that the purpose of *The REMR Bulletin* is information exchange and not the promulgation of Corps policy; thus guidance on recommended practice in any given area should be sought through appropriate channels or in other documents. The contents of this bulletin are not to be used for advertising, or promotional purposes, nor are they to be published without proper credits. Any copyright material released to and used in *The REMR Bulletin* retains its copyright protection, and cannot be reproduced without permission of copyright holder. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. *The REMR Bulletin* will be issued on an irregular basis as dictated by the quantity and importance of information available for dissemination. Communications are welcomed and should be made by writing US Army Engineer Waterways Experiment Station, ATTN: Lee Byrne (CEWES-SC-A), 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, or calling 601-634-2587.

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Director

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